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GEORGIA INSTITUTE OF TECHNOLOGY
Engineering Experiment Station

PROJECT INITIATION

Date: ~~6/25/73~~

Project Title: Preliminary Study of Consumer Ice Machine

Project No.: A-1539

Project Director: Mr. J. F. Kinney

Sponsor: Munford, Incorporated; Atlanta

Effective . 5/21/73 . . . . . . . . . . Estimated to run until: 6/21/73 . . . . . . . .

Type Agreement: Standard Industrial dated 5/16/73 . . . . . . . Amount: $ 2,084.00 . . . . . . .

REPORTS: Summary Report

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# GEORGIA INSTITUTE OF TECHNOLOGY
## Engineering Experiment Station

### PROJECT TERMINATION

Date March 29, 1974

PROJECT TITLE: "Preliminary Study of Consumer Ice Machine"

PROJECT NO: A-1539

PROJECT DIRECTOR: Mr. J. F. Kinney

SPONSOR: Munford, Inc., Atlanta, Georgia

TERMINATION EFFECTIVE: March 19, 1974 (sponsor letter canceling project)

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A-1539

SUMMARY REPORT

PHASE I

# PRELIMINARY STUDY OF CONSUMER ICE MACHINE

EES/GIT Project A-1539

by

J. F. Kinney

Prepared for

Munford, Inc.

Under

Georgia Tech Standard Industrial Agreement

5 July 1973

Summary Report

# PRELIMINARY STUDY OF CONSUMER ICE MACHINE

## Introduction

There exists a significant and growing market for packaged ice and hence a growing need for the equipment used to produce packaged ice. Moreover, health officials are concerned with the present types of ice machines used in many motels, because of problems associated with maintaining cleanliness and preventing contamination by vandals or careless consumers. Thus, an improved machine would also offer the potential of exploiting the motel market area, either by selling pre-packaged ice to the motels, or by selling them small packaged-ice vending machines.

The sponsor has estimated a need for 50-150 tons/day of ice-making capability by Spring, 1974. Existing equipment costs (new) about $2,100 per ton of daily ice producing capacity, and the price is increasing. Development of an improved variation of the present ice-making concept offers the potential of reduced overall capital investment, better reliability, and new markets for an improved ice machine.

A successful program must have a prototype unit completed for testing by early November, 1973. This is necessary to provide the lead time associated with fabrication of new units which must be ready for plant installation in time for the 1974 summer season.

## Approach

The sponsor's requirements for the design of a new machine are:

1. Twenty-four hour operation (unattended for at least 10 to 12 hours a day).
2. Dry ice is required (less than 10-15% snow and water).
3. Normal maximum unit size of approximately 15 tons per day.
4. Recirculation of the ice-making water.
5. Defrost-water recirculation and warming.
6. Capability for producing clean, clear ice.
7. Size of ice for marketing, roughly equal to the volume of a 3/4-inch to 1-inch cube.
8. It is desired that, at least initially, rectangular or cubed ice be considered the product.

The program proposed by EES to develop an improved consumer ice machine consists of four phases:

Phase I - Preliminary Study
Phase II - Prototype Design
Phase III - Prototype Fabrication and Assembly
Phase IV - Prototype Testing.

Phase I, study of the open literature and development of a preliminary approach to the design, has been completed, and is reported herein.

## Summary of Phase I

The open literature was examined, using the facilities of the Georgia Tech Price Gilbert Memorial Library. This study revealed numerous varieties of automatic/continuous ice manufacturing equipment, such as plate ice, flake ice, pak-ice, ice-tubes, etc. The primary reference to "cube" ice has been in regard to ice-trays with mechanical inverting for harvesting. A few references were found to square-tube ice which is subsequently sawed or wire cut to obtain the cube form. There are also a number of references to wire-cut cubes from plate ice.

The apparent art of making cube ice using vertical, compartmentalized evaporators does not appear to have been published to date.

Refrigeration equipment has not in general received the developmental attention that has been evidenced in some other industries, such as the electronics industry. Some changes have been made, but these are generally reflected with some variation in the equipment produced by most manufacturers. Automatic, self-cycling, timer-controlled equipment has become available from several sources. The vapor-compression cycle has apparently replaced the gas-absorption cycle for essentially all but air-conditioning duty.

## Design Approach

It is planned that the overall system will be assembled from commercial components, with the exception of the evaporator which will either be fabricated or assembled in the EES shop. The commercial components will be purchased by the sponsor upon recommendation of EES and will include the compressor/motor, condenser, receiver, expansion valves, heat exchanger (subcooling), and miscellaneous tubing, fittings, and valves. It is anticipated that these will be similar, and in some cases identical, to components currently used by the sponsor. The advantages of interchangeable components and common warehouse stocking are obvious.

With plate ice producing equipment, the time associated with the freezing period is

$$\theta = A\ (t + Bt^2)$$

where $\theta$ = time, minutes
$t$ = ice thickness, inches, and
$A$ and $B$ are constants.

The thicker the ice, the longer the time required per cycle. Because of the squared term, the rate of ice build-up decreases rapidly with thickness.

An optimum set of "cube" dimensions needs to be determined in terms of production factors and of the properties of the resulting product to the ultimate consumer. The sponsor has indicated a desire for a "cube" volume equivalent to that of a 3/4- to 1-inch cube. This range of volume provides some latitude in adjustment of dimensions. A useful measure of the "cube's" properties is the area-to-volume ratio. Presume that two dimensions (x in Figure 1) are to be made equal to one another, and the third dimension, the "thickness" (y in Figure 1), is to be varied. Then, for fixed x, reducing y increases the area/volume ratio, as seen in the graph of Figure 1. Increasing the ratio (decreasing thickness) will decrease the freezing time in production, a desirable trend. Increasing the ratio will increase the quickness-of-cooling

| 'Cube' Dimension (in) | Area ($in^2$) | Volume ($in^3$) | Area/Volume ($in^{-1}$) |
|---|---|---|---|
| 1 x 1 x 1 | 6 | 1 | 6 |
| 1 x 1 x 7/8 | 5.5 | 0.875 | 6.29 |
| 1 x 1 x 3/4 | 5 | 0.75 | 6.67 |
| 1 x 1 x 5/8 | 4.5 | 0.625 | 7.2 |
| 7/8 x 7/8 x 7/8 | 4.59 | 0.67 | 6.86 |
| 7/8 x 7/8 x 3/4 | 4.16 | 0.57 | 7.24 |
| 7/8 x 7/8 x 5/8 | 3.72 | 0.48 | 7.79 |
| 3/4 x 3/4 x 3/4 | 3.38 | 0.42 | 8 |
| 3/4 x 3/4 x 5/8 | 3 | 0.35 | 8.5 |
| 5/8 x 5/8 x 5/8 | 2.34 | 0.24 | 9.61 |

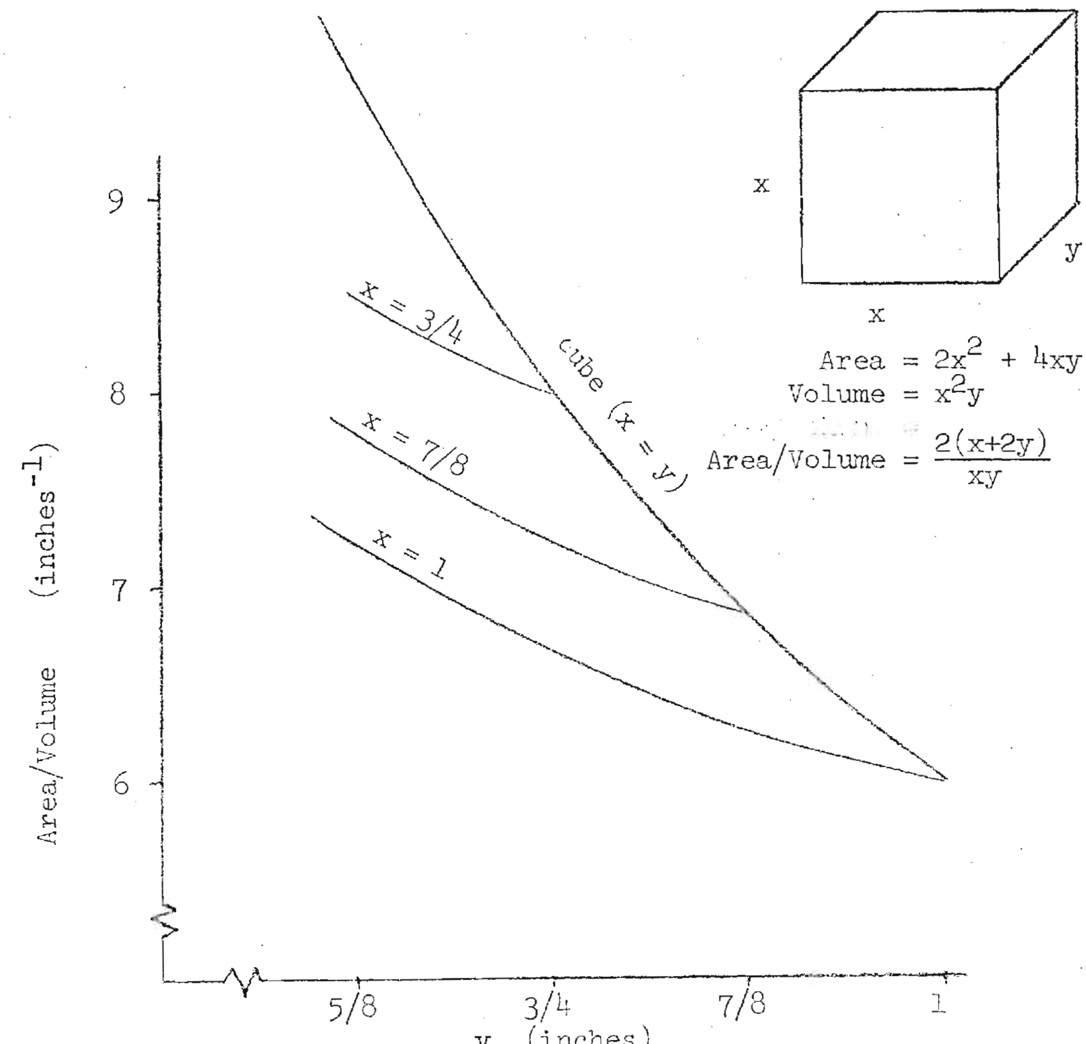


Figure 1. Area/volume ratio as a function of odd "cube" dimension.

experienced by the ultimate consumer when the cubes are used to cool drinks. This is also desirable, up to a point. Flake-ice naturally has a very high area/volume ratio, but the sponsor has indicated that this configuration is not desirable. Thus, there should be an optimum set of dimensions, and that optimum needs to be established prior to design of the evaporator for the prototype machine.

One approach would be to utilize plate-ice type equipment with the ice side compartmentalized. Using 1-inch squares and freezing to ½-inch thickness, the freezing cycle time should be very near that realized on present plate ice equipment. Harvesting and freeze-water distribution would be major considerations in the design. It is noted that all the heat extraction for freezing the water is obtained through the ice plate, and the rate of ice build-up decreases rapidly as the ice thickness is increased.

An alternative would be to incorporate the evaporator "coils" into the sides of the ice-cube forms, whereupon the freezing would occur from the sides as well as from the plate. This technique probably has a greater initial cost and also involves some problems with freezing water distribution. Defrosting would probably require the reverse cycle technique, where hot refrigerant gas would be used in the evaporator coils to release the cubed ice product. Because of the greater area (2 or 4 sides) available for transfer of the latest heat, freezing time may possibly be reduced, permitting more freezing cycles per day.

It is planned to construct from three to five small sections (6 inches x 15 inches) of the compartmentalized freezing unit, each by a different technique. These sections will be tested by placing each in the system (replacing the evaporator) of a small air conditioning unit, adjusted for the appropriate evaporator temperature. This will serve to evaluate the various heat transfer coefficients, water distribution, and ice harvesting problems. These three factors and the associated fabrication costs of the evaporator should permit selection of the type of ice-cube freezing unit to be used in the prototype unit.

## Time Schedule

The time schedule to design and assemble a prototype 15-ton ice-cube machine for testing in early November, 1973, is outlined in Figure 2.

## Conclusions

1. The art associated with making cube-ice using vertical compartmentalized evaporators does not appear to have been published to date.
2. Use of commercial components for all units of the cube-ice-making equipment appears practical, with the exception of the evaporator.
3. Three to five test sections of the compartmentalized evaporator are required to develop the necessary data for selection of a satisfactory evaporator design for the prototype.
4. The time schedule to provide a prototype 15-ton ice cube machine for testing in early November, 1973, appears to be tight, but realistic.

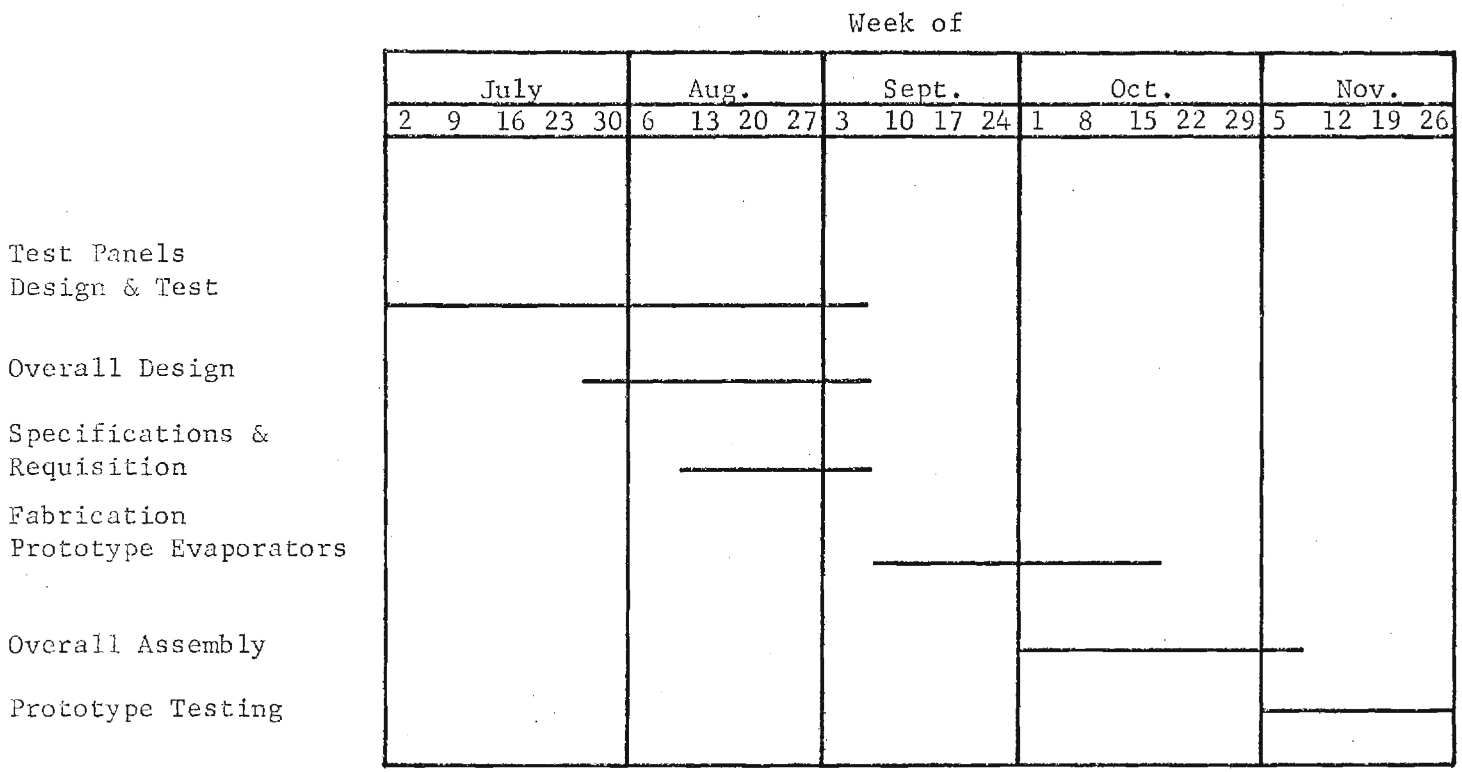


Figure 2. Estimated Schedule.

Recommendations

It is recommended that:

1. The Phase II effort be initiated immediately if the November deadline is to be realized.

2. Commercial components, purchased by Munford, Inc. on the recommendation of EES, be used for all units in the ice machine with the exception of the evaporator.

A-1539

20 November 1973

# SUMMARY REPORT

## CONSUMER ICE MACHINE - PHASE II

## EES/GIT Project A-1539 for Munford, Inc.

### I. Summary

Development of a consumer ice machine capable of making 15 tons/day of ice in the form of cubes having a volume of one cubic inch, is well underway. The vertical evaporator, with freeze water flowing down the face of the evaporator, appears feasible. Harvesting by means of hot refrigerant gas is practical. The two most obvious means of fabricating the evaporators are not economically practical, namely, (a) the electroforming process, which requires significant post machining of the electroform; and (b) the explosive forming operation, which is not feasible in 30 x 60 inch plates requiring a 1-inch depth of draw. However, roll-forming of standard copper tubing to form the trapezoidal shape for the horizontal grids is both feasible and economical. A small experimental unit should be constructed, similar in all details to that anticipated in the prototype, and tested prior to fabrication of the prototype.

### II. Experimental Work

A total of eight experimental evaporators have been constructed, tested and evaluated.

1. A 6-cube by 15-cube evaporator, with a stainless-steel grid and back plate was prepared with a copper serpentine coil brazed to the back plate. This unit not only required some 40 to 60 minutes to make the ice, but produced uneven amounts of ice in the cubicles, those directly in front of the copper refrigerant coil producing full cubes, those between the copper coil, only partly filled cubes. In general, the heat transfer rate was significantly below the rate required for the prototype unit, and bridging of the ice between the cubes was severe.

2. A 6-cube by 15-cube brass plate and grid evaporator was constructed, with a copper serpentine coil brazed on the back plate. The first unit of this type was made by silver-soldering the refrigerant coil to the back plate - with only a very thin bead of solder between coil and plate. This thin solder bead

was insufficient to achieve the heat transfer required. A second unit which had a 1/4-inch wide bead, produced a full tray of ice in 20 minutes; harvest was readily accomplished with hot water, but bridging was severe.

3. A 6-cube by 15-cube evaporator was fabricated using a copper-grid, brass plate, and copper serpentine refrigerator coil brazed to the back plate. The lower 4 horizontal ribs were triangular in cross-section (3/4 inch high, with 1/32 inch radius at top and a 1/4 inch width at the bottom where the rib was brazed to the plate, approximately $7^{o}$ half-angle). This unit produced a full tray of ice in 14-15 minutes. A 100% harvest was obtained using $130^{o}$ water and then rotating the plate unit $12^{o}$ back (although bridging between cubes was severe).

   This unit was also tested in the inverted horizontal mode, spraying water into the inverted cubicles. Spray distribution was not uniform, ice cubes were formed in 14 minutes but bridging was severe. Harvest was achieved with the installation of a hole in the back plate of each cube to relieve the suction associated with the ice cube dropping out of the cubicle.

4. A 5-cube by 10-cube electroformed evaporator was produced in which the refrigerant could circulate on four sides of each cube. The unit was too large for the experimental electroform tank at Georgia Tech, requiring an unrealistic time in forming, and the low current (50 ampere capacity) did not produce the proper surface finish. This unit had several small leaks in the corners of the grids. In an attempt to seal these leaks, the unit was dipped in hot solder. The operator dropped the experimental unit twice, and in grabbing it, punched holes in the thin-walled sides. By judicious cutting we saved a 5 x 5 cube section for subsequent testing. The unit produced ice in 10-12 minutes, but was not free harvesting because of irregularities in the surface finish.

   A smaller (5 x 5 cube) unit was produced, which was also too large for the Tech electroforming equipment. The unit also had some surface irregularities, requiring both machining and hand finishing. While ice production was still achieved in 10-12 minutes, no reliable harvest was obtained, and bridging was severe.

5. A 5-cube by 5-cube evaporator was fabricated using 0.031-inch strips formed into a 1-inch high, 1/4 x 7/16 inch trapezoid bars, which were soldered to a copper plate forming the horizontal grids. Vertical grids were cut to fit from 0.031 copper sheet, and soldered into place to form the 1-inch high by 0.94 by 1-1/8 by 1-1/4 inch cubes. The horizontal grids were connected by a 1 x 1/2 inch square manifold at each side. This evaporator made ice in 9-12 minutes, water distribution required some adjustment, and harvest was obtained with hot gas in 3-4 minutes. Silicone rubber strips were molded in Teflon and placed on the crest of the horizontal strips to prevent bridging vertically. Bridging between horizontal adjacent cubes is still obtained, but if the row of ice cubes falls 6-8 inches, separation of the cubes is obtained.

6. A 5-cube by 5-cube evaporator was formed from 1 by 1/2 inch rectangular tubing by deforming one end to produce a 1/4 inch wide section. These triangular shaped tubes were then brazed horizontally on a copper plate and connected to a 1 by 1/2 inch rectangular manifold. This unit also had the molded silicone rubber anti-bridging strips cemented to the horizontal bars. Ice was made in 10-12 minutes and harvest achieved in 3-5 minutes. Again some bridging occurs horizontally between the cubes, but no vertical bridging appears to be obtained. The water flow can be adjusted to produce the necessary distribution.

## III. Results

These tests suggest that: (1) to achieve a unit of reasonable size, copper or copper/brass should be used in the evaporator for all heat-transfer surfaces; (2) circulation of the refrigerant in the cube walls as contrasted to the serpentine coil on the back plate significantly increases the rate of ice formation; (3) a vertical evaporator is feasible; and (4) tapering the cube sides, at least the horizontal sides of the cubes, is helpful from the standpoint of water distribution and from that of harvesting.

The concept of an electroformed grid with refrigerant circulation around four sides of the cube provides near-maximum heat transfer area. The electroforming process however, does not appear to lend itself to large-piece mass production. Discussions with one of the relatively few artists in electroforming indicate that some of the post-electroform machining operations can be reduced by proper attention to electrode configuration, current density, electrolyte flow, and copper concentration in the electrolyte. However, some additional final machining would still be required on the plates, which could be accomplished with automatic equipment but would have to be manually set up and adjusted.

The other major potential technique for forming this type of grid would be an explosive forming process. Lockheed California advised that the cubes are too deep and the piece 31 x 62 inches is too large to be economically produced by this process.

Another alternative would provide refrigerant chilling on two sides of the cube rather than four, much as experimental evaporators 5 and 6. This technique would consist of rolling conventional copper tubes to the trapezoidal shape, brazing the tubes to the back plate, and using a series refrigerant flow through the tubes. It is believed this manufacturing technique can be used with effectively a dip-brazing operation to produce the evaporator, believed to be required, in a semi-production operation.

A second alternative is to form the horizontal strips as in experimental unit No. 5, brazing to the back-plate, and then attaching refrigerant flow tubes to the ribs to feed the refrigerant flow to the ribs in series connection. This would require an increased amount of hand work to perform all the brazing (soldering) required over that associated with the above technique, but would result in a satisfactory evaporator unit, having triangular shaped horizontal ribs to facilitate the harvest operation.

## IV. Conclusions

The following conclusions have been reached as a result of the Phase II experiments.

1. Ice can be formed readily in a vertical evaporator in cubical form with a volume of one inch.
2. Harvesting can be accomplished, provided the horizontal ribs have a triangular shape.
3. Harvesting will require a hole in the back plate to relieve the suction when the ice cube is moved out of the cubicle.
4. The electroform type of grid is desirable to produce freezing from four sides of the cube.
5. The electroforming process is not suited to economical production of large units because of the post-machining operations.
6. The alternative technique of explosive forming of the grid is not economically practical in 30 x 60 inch units.
7. Freezing of the cube from 2 sides instead of 4 sides does not significantly increase the time required for the freezing process.
8. Manufacture of an evaporator using the two-sided freezing process appears to be practical and economical.

## V. Work To Be Done

1. Rolling of standard sized tubing to produce the required triangular shape appears to require a relatively minor adjustment of the rolling-mill. This needs to be confirmed and a trial run accomplished to fabricate an experimental unit.
2. Evaluation of the productivity of an experimental unit should be accomplished to confirm the anticipated size required of the prototype to produce 15 tons/day.
3. Fabrication and assembly of the prototype unit.
4. Testing, evaluation, and adjustment of the prototype unit to produce 15 tons/day of ice.